

Piping can also occur in natural settings, typically when sheetwash erosion (see “Sheetwash Erosion” section) starts to concentrate into rill erosion, entering a soil through cracks, animal burrows, fence- post holes, or excavations, and eventually moving through the subsurface to an exit point (Pete Biggam, NPS soils scientist, e- mail communication, February 23, 2007). Pipes are most common on and near the base of steep slopes at Theodore Roosevelt National Park (figure 11). The principal danger associated with erosional pipes is roof collapse (Biek and Gonzalez 2001).

### Swelling Soils and Bentonite

Sixty million years ago, volcanoes erupted far to the west of Theodore Roosevelt National Park spewing ash into the atmosphere. Rivers and wind transported and deposited this ash across the northern Great Plains. Chemical weathering altered the ash into bentonite—soft, malleable clay that is composed largely of smectite. As mapped by Biek and Gonzalez (2001) in Theodore Roosevelt National Park, bentonite of the Sentinel Butte Formation appears as bluish colored bands in the badlands. These beds can be traced for miles along the

Little Missouri River (figure 12). When wet, bentonite can expand up to 16 times in volume. The inherent swelling and shrinking of bentonite can cause structural damage to buildings, roads, and other infrastructure. Wet bentonite produces slippery, hazardous conditions cross country and on trails and roads. Upon drying the clay contracts and forms the “popcorn” surface characteristic of bentonite.

Bentonite is also an economic resource, though the small deposits in North Dakota are unlikely to be of economic value (Biek and Gonzalez 2001). Bentonite is added to drilling mud to cool cutting tools, remove cuttings, lubricate drill bits, prevent blowouts, and confine underground fluids by creating an impervious coating. Moreover, bentonite is used as a binder for foundry sand and for pelletizing iron ore. It also serves as a sealant or liner for landfills, ponds, and canals. It is an additive used as a filler, stabilizer, or extender in materials such as adhesives, greases, medicines, cosmetics, paint, rubber, and soaps. Most of the bentonite used in the United States comes from Wyoming.

**Table 1. Geologic Time Scale**

Eon	Era	Period		Epoch	Age (Ma)	Age of
Phanerozoic	Cenozoic	Neogene	Quaternary	Holocene	0.01	Mammals
				Pleistocene	1.81	
		Paleogene	Tertiary	Pliocene	5.33	
				Miocene	23.0	
				Oligocene	33.9	
				Eocene	55.8	
				Paleocene	65.5	
				Mesozoic	Cretaceous	
	Jurassic		199.6			
	Triassic		251.0			
	Paleozoic	Permian		299	Amphibians	
		Carboniferous	Pennsylvanian	318		
			Mississippian	359.2		
		Devonian		416.0	Fishes	
		Silurian		443.7		
		Ordovician		488.3	Invertebrates	
		Cambrian		542.0		
	Proterozoic	Also known as Precambrian				2,500
Archean	3,800?–2,500					
Hadean	4,600?–3,800					

*Notes:* Dates are in millions of years (Ma) and indicate the beginning of each associated period or epoch. Dates reflect the International Union of Geological Sciences (IUGS), International Stratigraphic Commission (ICS), International Stratigraphic Chart (2004) at <http://www.stratigraphy.org/down.htm>. The International Stratigraphic Commission does not list the boundary between Archean and Hadean. However, the U.S. Geological Survey lists this boundary at approximately 3,800 Ma and the formation of Earth at approximately 4,600 Ma, which are used here. Mississippian and Pennsylvanian are terms used primarily in North America. Tertiary is no longer used by the International Commission on Stratigraphy (2004) but is listed here because it is still in common use.